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Volume 3
Final Report
Requirements
D180-27477-3

3

Space Station Needs, Attributes, and Architectural Options Study

Arthur D. Little, Inc. | Battelle | Life Systems, Inc. | HAMILTON STANDARD | Division of United Technologies | RCA

Environmental Research Institute of Michigan | INTERMETRICS | Microgravity Research Associates, Inc. | NBBI | SAI | Econ

Space Station
Needs, Attributes and Architectural Options Study

Contract NASW-3630

D180-27477-3

Final Report

Volume 3

Requirements

April 21, 1983

for

National Aeronautics and Space Administration

Headquarters

Washington, D. C.

Approved by Gordon Woodcock

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FOREWORD

The Space Station Needs, Attributes and Architectural Options Study (Contract NASW-3680) was initiated in August of 1982 and completed in April of 1983. This was one of eight parallel studies conducted by aerospace contractors for NASA Headquarters. The Contracting Officer's Representative and Study Technical Manager was Brian Pritchard. The Boeing study manager was Gordon R. Woodcock.

The study was conducted by Boeing Aerospace Company and its team of subcontractors:

Arthur D. Little, Inc. (ADL)	Materials Processing in Space
Battelle Columbus Laboratories	Materials Processing in Space
ECON, Inc.	Pricing Policies and Economic Benefits
Environmental Research Institute of Michigan (ERIM)	Earth Observation Missions
Hamilton Standard	Environmental Control and Life Support Equipment
Intermetrics, Inc.	Software
Life Systems, Inc. (LSI)	Environmental Control and Life Support Equipment
Microgravity Research Associates (MRA)	Materials Processing in Space
National Behavioral Systems (NBS)	Crew Accommodations and Architectural Influences
RCA Astro-Electronics	Communications Spacecraft
Science Applications, Inc. (SAI)	Space Science

This document is one of seven final report documents:

D180-27477-1	Volume 1, Executive Summary
D180-27477-2	Volume 2, Mission Analysis
D180-27477-3	Volume 3, Requirements
D180-27477-4	Volume 4, Architectural Options, Subsystems, Technology, and Programmatics
D180-27477-5-1	Volume 5-1, National Defense Missions and Space Station Architectural Options Final Report (SECRET)
D180-27477-5-2	Volume 5-2, National Defense Missions and Space Station Architectural Options, Final Briefing (SECRET)
D180-27477-6	Volume 6, Final Briefing

D180-27477-7-1	Volume 7-1, Science and Applications Missions Data Book
D180-27477-7-2	Volume 7-2, Commerical Missions Data Book
D180-27477-7-3	Volume 7-3, Technology Demonstration Missions Data Book
D180-27477-7-4	Volume 7-4, Architectural Options, Technology, and Programmatics Data Book
D180-27477-7-5	Volume 7-5, Mission Analysis Data Book

Note: The volume 7 data books will be distributed to a limited number of requestors.

The study task descriptions and a final report typical cross reference guide are found in Appendix 1.

The Boeing and subcontractor team member are listed in Appendix 2.

Acronyms and abbreviations are listed in Appendix 3.

CONTENTS

ILLUSTRATIONS

INTRODUCTION

It is recommended that the Space Station System Requirements be prepared and published in the format of a System Specification.

The objectives in preparation of the Volume 3 Requirements Document are to present a typical system specification format and to compile requirements not previously published and derived during this study.

A Program Specification Tree is shown in figure 1 showing a high inclination space station and a low inclination space station with their typical element breakdown, also represented along the top blocks are the interfaces with other systems. The specification format is directed at the Low Inclination space station.

REQUIREMENTS COMPILATION

The primary thrust of the Space Station Needs, Attributes, and Architectural Options Study was to identify and validate the user community mission requirements. Mission Requirements Data Sets were defined in the following five areas.

Science and Technology
Commercial
Technology Development
Space Flight Operations
National Security

These data were the basis for a programmatic mission requirements set logically evolved through benefits/economic analysis. The requirements are fit within a reasonable budget profile, are responsive in a schedule/phasing sense, and yield important benefits. These mission requirements establish the recommended orbital mission characteristics and the complementing experiment program.

Further study requirement activity has been directed at collecting a set of crew and habitability requirements that is based upon long duration space flight accomplished to date. National Behavior Systems, under subcontract to Boeing, performed an intensive survey of those individuals that have been directly involved in long duration space flight, i.e., Apollo, Skylab,

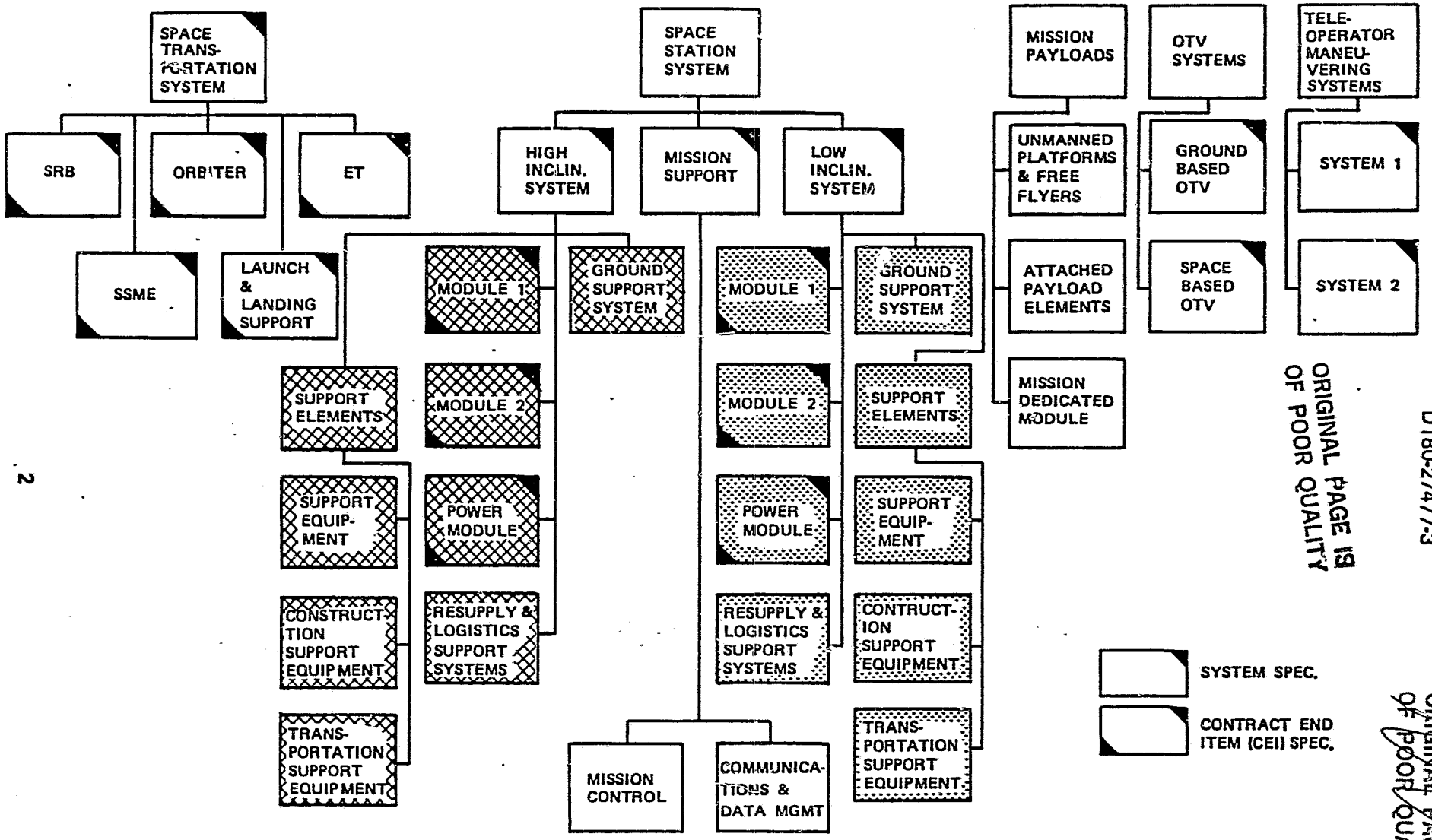

Figure 1. Program Specification Tree

and Space Shuttle programs. A compilation of Habitability and Crew Support Requirements from this effort is included in this System Requirements Document.

RECOMMENDED FORMAT FOR SYSTEM SPECIFICATION

The NASA Space Station System Requirements Working Group recently published Reference 1 which is the first edition of the Space Station System Requirements Document. It would benefit the program to reformat Reference 1 in the form of a System Specification. This volume is presented in the suggested system specification format.

It is an aid to requirements definition to initiate development of the system specification in parallel with the definition of the system. Flexibility exists for NASA to mold the format to fit the system as the requirements are defined. When a system specification is needed for procurement and development of Contract End Items (CEI) it becomes an editing task for NASA to issue the system specification with full confidence that it represents the top system requirements in a workable format for CEI development and contracting.

It was not deemed productive for us to convert Reference 1 to this system specification format until NASA has agreed to the approach and in particular has approved/adjusted the format. The only areas of Reference 1 that have been duplicated herein are the Programmatic Ground Rule sections of Growth Capability, other requirements presented herein are additive to Reference 1.

The requirements of Reference 1 are referenced by paragraph number in italics within the proposed system specification format.

Analysis of the mission requirements data sets suggests that a space station at low inclination and another at high inclination satisfies the bulk of the mission needs. In this particular case two system specifications would be required for (1) a high inclination space station and (2) a low inclination Space Station. This would result in many Contract End Items that are common to each space systems as defined in figure 1.

The resulting System Specification would probably be separated into volumes because of the bulk of the document. For example the following sections would lend themselves to be contained in separate volumes:

3.2.2.1 Space Systems Design
3.2.2.2 Ground Systems Design
3.2.5 Space Station System Interface
3.3 Space Station System End Item Performance
3.4 Ground Complex Performance and Design Characteristics

The mature system specification would, in this case, be a six volume set.

LOW INCLINATION SPACE STATION
SPACE STATION SYSTEM REQUIREMENTS

1.0 SCOPE

This Requirements Document is formatted to provide the development of a System Specification for the Space Station System. It is intentionally non-redundant with the NASA Space Station Program Description Document - System Requirements and Characteristics, Book 3. Your attention is directed to the Reference and Design Characteristics, Section 3.2, and Space Systems Design (starting with Section 3.2.2.1) for our recommended requirements.

This document contains the system requirements for a low-Earth-orbit (LEO) manned Space Station that will operate with other complementary space systems to provide significantly increased effectiveness in support of a wide range of missions with objectives in science, applications, commercial operations, national security, technology development, and overall space operations. To meet these objectives, the Space Station shall be permanent and shall provide:

a. Facilities and services for science and applications, technology development and commercial activities,
b. A base for assembly, service, storage, launch, and recovery of unmanned/manned orbit transfer systems,
c. Facilities for assembly, construction, service checkout, launch, and recovery of increasingly large and complex systems in LEO, and
d. Manned presence for developing space-based national security activities.

The requirements for the interfaces between the Space Station and the other space systems that interact with the station are included. These interacting elements include the Space Transportation System (STS), orbit transfer systems, unmanned platforms, free-flying satellites, and other related elements.

1.1 SYSTEM FUNCTIONAL DEFINITION AND END ITEM DEFINITION *(Para. 2.1)**

The Space Station is a low-Earth-orbit facility that will operate with complementary, interfacing space systems to support various manned and unmanned space operations defined herein beginning in 1990. The services and equipment provided by the Space Station shall

include provisions for orbit management and attitude control; electrical power and consumables required for mission equipment and housekeeping; flight personnel to support the management equipment and housekeeping; flight personnel to support the management of mission systems; communication and information systems for onboard systems management and user interaction; accommodations for onboard experiments; and provisions for the maintenance, checkout, and storage of space hardware and consumables. The Space Station shall consist of an assembly of modules; each module shall be capable of being transported to the desired low Earth orbit in the Space Shuttle. The assembly shall be designed to be assembled in orbit.

(Top Level Functional Block Diagram TBD)

1.1.1 Space Station System Functions

(Reference to Functional Block Diagram)

2.0 Applicable Documents

(Reference list to be added)

*Paragraphs noted in italics are corresponding paragraphs in the NASA requirements document.

3.0 REQUIREMENTS

The requirements are specified for a Low Earth Orbit (LEO) Manned Modular Space Station. This Space Station is assembled in orbit with elements transported to LEO by the Space Transportation System.

3.1 SPACE STATION DEFINITION

Programmatic Requirements and Guidelines are defined for the Space Station configuration and operations. Space Station system elements are specified and described and ground operations elements are specified and described.

Control characteristics for the on orbit integrated configurations are specified. (Element characteristics are defined in Paragraphs 3.3.1, 3.3.2, 3.3.3 and 3.4 respectively).

3.1.1 Configuration Requirements and Guidelines

3.1.1.1 Development and Buildup *(Para. 2.2)*

The Space Station and its interfacing elements shall provide phased development and incremental buildup in capability to fulfill mission requirements on a time-phased basis. The Space Station design shall provide phased increases in capability that can be matched to the demand for space-based services. Each program phase shall establish a significant increase in U.S. manned space capability and should be justifiable on a stand-alone basis if necessary. Modularity at both the module and subsystem level shall be emphasized as a means of accomplishing this flexibility and as a means of accommodating budget constraints.

3.1.1.2 Initial Capability *(Para. 2.3)*

The initial Space Station shall provide the following capabilities:

a. Manned occupancy with a crew of TBD for TBD days between planned Orbiter visits. Manned occupancy shall be the normal mode of operation; however, under certain TBD circumstances, the Space Station shall be capable of unmanned operations under ground control.

b. Provisions for attached payload packages or pressurized mission-dedicated modules.

c. Facilities for servicing co-orbiting satellites in the near vicinity of the Space Station.

d. Support for (TBD size) free-flying (detached) science and applications payloads attached to co-orbiting platforms including individual payload changeout.

e. Laboratory or workshop capability including interior pressurized space for small self-contained payloads.

f. Fluid transfer capability to replenish Space Station consumables.

g. Stage assembly, checkout, and launch capability (not including fueling or refueling of stages).

h. Capability for the support of assembly and/or deployment of large systems.

i. Capability to function as an orbital test bed to support Space Station evolution/growth.

3.1.1.3 Growth Capability *(Para. 2.4)*

Growth versions of the Space Station shall provide expanded habitability, increased provisions or supporting access to geosynchronous orbit, and increased capabilities to perform other functions initiated in the initial phase of buildup. Specific capabilities include the following:

a. Extended servicing capability for co-orbiting satellites and platforms
b. Orbit transfer vehicle (OTV) servicing and launch capabilities
c. Construction and assembly of large space structures
d. Increased capability for the support of assembly and/or deployment of large systems
e. Increased capability to function as an orbital test bed
f. Increased habitation for additional crew
g. Extended provisions for increased numbers of attached payload packages and mission-dedicated modules

3.1.2 Operations Requirements and Guidelines

3.1.2.1 Space Station Orbital Operations

3.1.2.1.1 Space Station Buildup *(Para. 2.8.1.1)* The delivery of various Space Station systems elements to orbit will be accomplished by the STS. Initial assembly, activation, checkout, and operational verification tasks will be shared by the STS in a Shuttle-tended mode, the Space Station flightcrew, and ground control. Crew occupancy will occur after the manned system is verified and will consist of a crew rotated by the STS every TBD days. As operational confidence is achieved in the various elements, ground support of their operation will be phased to an effective mix of onboard control and ground control. Expendables and spares will be periodically carried to the station in a logistics module by Shuttle resupply missions.

3.1.2.1.2 Orbital Operations *(Para. 2.8.1.2)* Orbital operations will include operating and servicing internal and externally attached experiments/payloads/laboratories, operating and servicing the unmanned platform-mounted experiments/payloads, servicing of payloads and free-flyers, test and deployment of payloads and upper stages, national security and commercial operations, and eventual large-scale construction/assembly of payloads. The manned Space Station will operate cooperatively with the unmanned platforms and their attached instruments, experiments, and payloads by providing systems monitoring and control, data and material collection, and systems/instrument replacement and refurbishment.

3.1.2.1.3 Space Station Orbital Operations Requirements *(Para. 2.8.1.3)*

A. Evolutionary development - Evolutionary development during the life of the Space Station shall be required as a major operational and design consideration.

B. Operations - The manned station is intended to operate in the manned mode. Unmanned operations at the manned station will, as a minimum, consist of (1) maintenance orbit, attitude, and systems, and (2) continuation of certain essential services to attached payload hardware.

The system shall operate in Shuttle-tended modes for material and crew resupply and for delivery of Space Station elements and delivery/return of payloads.

Subsystems shall be automated to the fullest extent practical. The flightcrew of the ground shall be able to change automated sequences and limits in real time.

System design and operation shall allow use of the flightcrew for the performance of tasks when man's capability and utility could provide a cost-effective alternative to automation.

Management of Space Station system operations (both manned and unmanned elements) shall be divided between the flight system and the ground system to most effectively utilize the capabilities of each.

Continuous subsystem monitoring and control by either the flightcrew or the ground shall not be required for normal Space Station operations. Space Station subsystems shall be designed such that any single credible failure will not require crew attention for a minimum of TBD hours and will not affect critical Space Station operations.

Provisions will be provided onboard to allow the crew to accomplish near term planning with a minimum of ground support.

3.1.2.1.4 End of Useful Life Disposal. Provisions shall be made for the safe disposal of the Space Station at the end of its useful life in orbit.

3.1.2.1.5 Payload and Mission Operations *(Para. 2.8.2)*

These paragraphs will define the Payload and Mission Operations Requirements and guidelines for manned operations, unmanned operations and user interfaces.

3.1.2.2 Ground Control/Support Operations *(Para. 2.8.3)*

These paragraphs will define the ground rules, guidelines and requirements as applied to the Ground Control/Support Operations.

3.1.2.3 Ground Operations *(Para. 2.8.4)*

The ground operations process and the requirements/objectives that must be met to demonstrate Space System performance are specified.

3.1.3 Space Station System Elements

This section defines and describes the Space System and ground operations system elements.

3.1.3.1 Space System Elements

1. *Module 1 (example)*
2. *Module 2 (example)*
3. *Power Module (example)*

3.1.3.2 Ground Operations System

1.
2.
3.

3.1.4 System Schematic - Block Diagram

This block diagram Figure 3.1.4-1 defines the Space System and its elements, the System Interfaces, and the Ground System Facilities.

3.1.5 Space Station System Weight and Performance Control

Control weights, moments of inertia, and overall configuration balance constraints are defined.

3.1.6 Integrated Space Station Configuration

The Space System integrated envelope and control dimensions are defined.

3.1.7 Commonality and Standardization *(Para. 2.6.10)*

The ground rules, guidelines and measurements for Commonality and Standardization are specified for the Space System as applied to modular elements, subsystems, subsystem elements and ground systems.

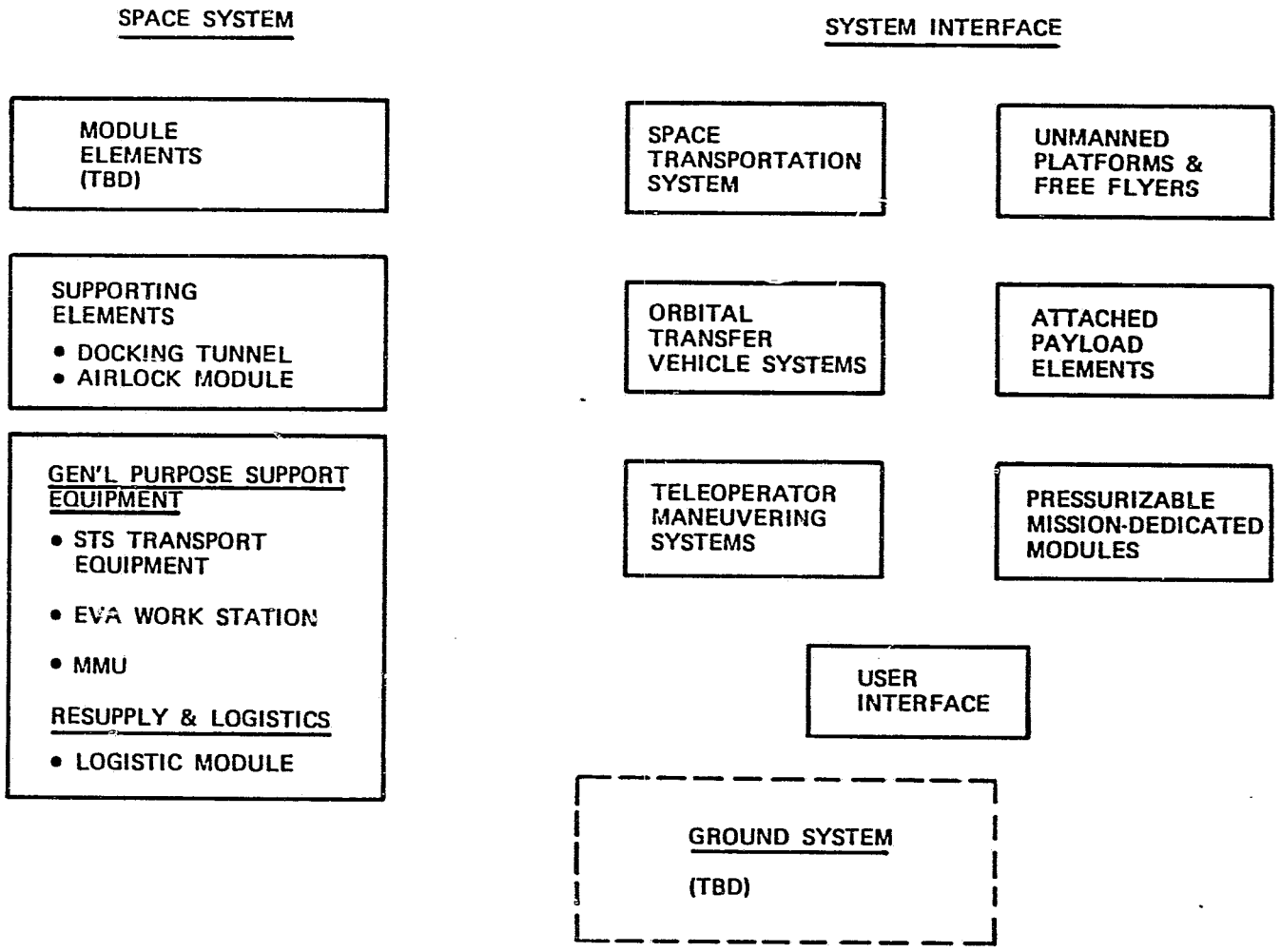

Figure 3.1.4-1. System Schematic Block Diagram

3.2 PERFORMANCE AND DESIGN CHARACTERISTICS

This section defines the Mission performance and Design Characteristics for the low inclination (28.5^{o}) Space Station System. The requirements are specified by subsystem, ground system design, logistics, personnel and training, and system interfaces.

3.2.1 Mission Performance

Mission accommodation requirements as defined by the mission model (Scenario A - Mission Driven) are defined in Volume 2, Section 4 and summarized in Figure 3.2.1-1. High inclination data is also provided as comparative information in Figure 3.2.1-2.

3.2.2 Design Characteristics

These paragraphs define the Space Station on orbit system and ground system design requirements as composed of integrated elements.

3.2.2.1 Space Systems Design *(Para. 2.6.6, para. 2.7)*

On orbit system requirements are defined by subsystems that involve the total on orbit Space Station assembly of elements. Included are natural and induced environments as referenced to appendix 10.1 and 10.2 respectively. Space Station System end item, system element performance characteristics and requirements are defined in section 3.3 for the on orbit system and section 3.4 for the ground complex.

3.2.2.1.1	Structures
3.2.2.1.2	Electrical Power Generation and Energy Storage
3.2.2.1.3	Electrical Power Distribution and Control
3.2.2.1.4	Environmental Control and Life Support Systems

3.2.2.1.5 EVA Support

A. The EVA airlock shall provide adequate volume for stowage of EVA equipment and for the suited crewman to function and maneuver. Available volume should provide adequate space for the observer during the donning and doffing of EVA suits.

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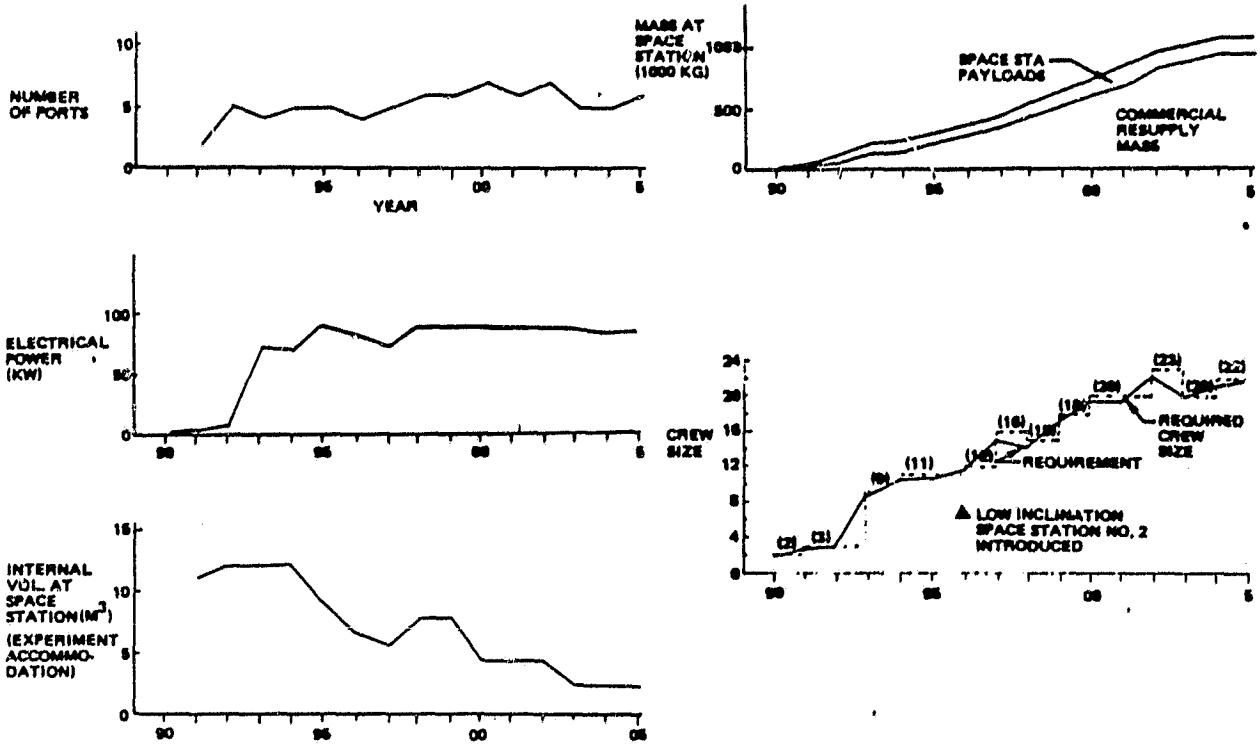

Figure 3.2.1-1. Low Inclination Mission Accommodation Requirements (Scenario A—Mission Driven)

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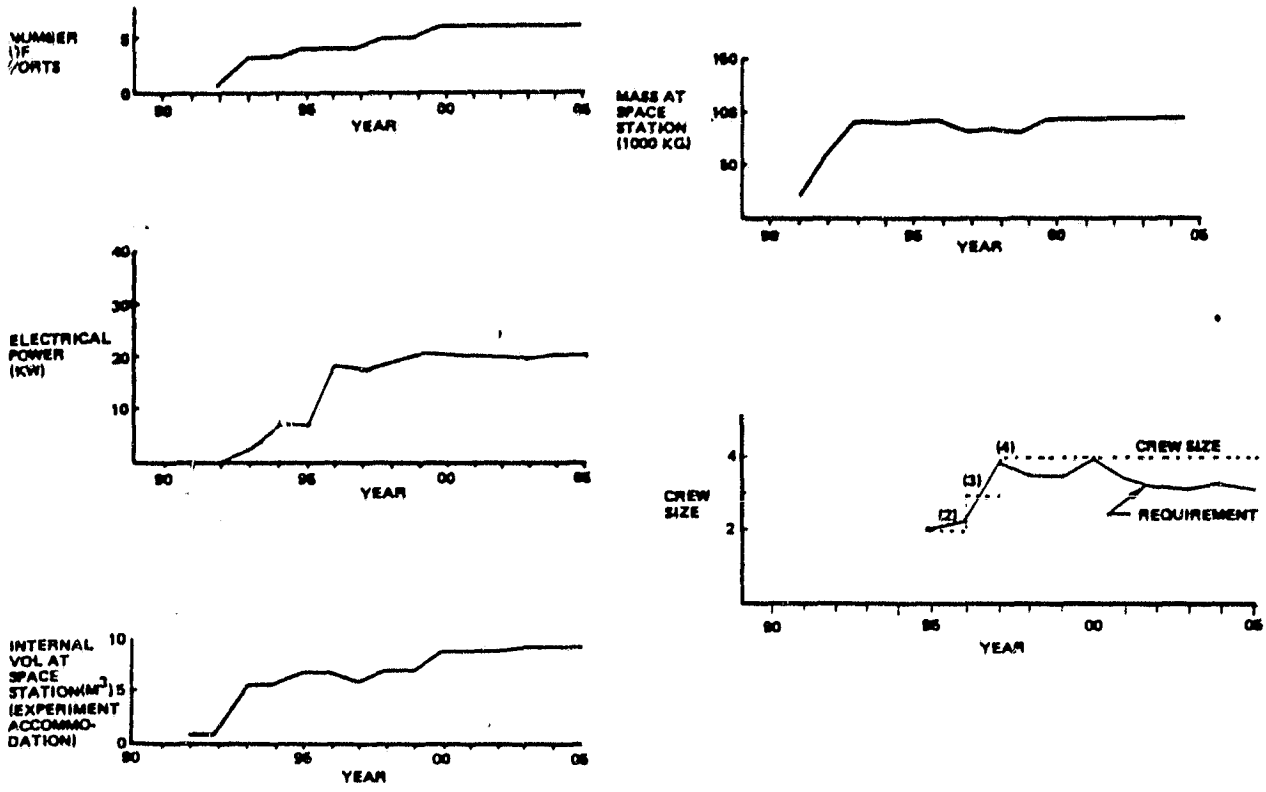

Figure 3.2.1-2. High Inclination Mission Accommodation Requirements (Scenario A—Mission Driven)

B. It is desirable that the EVA airlock be located as an appendage to the living/working areas.

C. Battle lanterns or equivalent shall be provided for the EVA lighting. They shall be mounted on rails and equipped with swivel or gimbal mounts.

D. EVA shall be considered a normal mode for repair.

3.2.2.1.6 Data Management *(Para. 2.9)*

A. An Inventory Management System that is alphabetical with cross categorization characteristics shall be provided. Standard terms shall be used for all items. All on-board inventory data format shall be standardized with real time uplink data format.

B. Displays and Controls shall be designed to avoid inadvertent actuation and damage of controls and displays due to impact by crewman and equipment during transportation throughout the space station.

3.2.2.1.7 Communications and Tracking

3.2.2.1.8 Docking/Berthing

3.2.2.1.9 Guidance, Navigation, and Control

3.2.2.1.10 Onboard Propulsion

3.2.2.1.11 Habitability and Crew Support

1. **Habitability**

The Habitability and Crew Support requirements defined herein are defined as a delta to requirements expressed in Paragraph 2.7.11 of Reference 2.

A. **Internal Environment**

(1) Respirable Atmosphere

(2) Lighting

(A) Each activity shall be provided with lighting controls for area lights. These controls shall be conveniently located to provide lighting adjustment as external orbital lighting conditions change.

(B) Night light route locators shall be provided in areas normally darkened for sleep or work.

(C) Lighting of personal hygiene areas shall be adequate for reading and cleaning.

B. **Space Architecture**

(1) **Arrangement**

(A) All walls and ceiling areas shall be usable for installation and stowage of equipment.

(B) Ceiling to floor heights may be reduced to 6 feet wherever greater equipment installation and stowage volumes are desired.

(C) The Space Station wardroom area shall be designed and sized for use as a central meeting, eating and recreation area. Food storage and preparation shall not be disruptive to its use as a wardroom and recreation area.

(D) The wardroom shall double as an Emergency Medical Facility for the Initial Space Station with storage for an Emergency Health Maintenance Facility Unit. This unit will be available in the Growth Station as a first aid station.

(E) Waste Management Facilities shall be located away from the Food Preparation Area. Privacy shall be emphasized in the arrangement and location. A location near the private crew quarters is desirable.

(F) Temperature and Ventilation Controls shall be provided in the Waste Management Facilities.

(G) Normal Translation Traffic routes shall not interfere with the working, eating, sleeping or relaxation of crewmen.

(H) A clear zone shall be established contiguous with each hatch and bulkhead opening, requiring all surfaces to be free of hardware protrusions, sharp corners and edges, and recesses or holes.

(I) Significant protrusions along main traffic routes shall be avoided.

(J) Unusable volume closeouts shall be designed to eliminate areas where debris and small items may be trapped or lost.

(K) A modularization architectural approach shall be considered for internal partitioning of modules.

(2) Interior Appointments

(A) The wardroom shall be equipped with chest high writing facilities and temporary storage. Basic wardroom equipment shall be a computer terminal and a large screen video unit with a video cassette.

(B) The finish applied to walls, ceilings, and equipment in the vicinity of work stations and traffic area shall be capable of withstanding significant abrasion and wear without noticeable deterioration.

(C) A color graphics system shall be adopted to indicate storage areas, affording easy recognition from any position, distance and lighting conditions.

(D) Tables, consoles, work stations and writing stations shall be chest height and equipped with foot restraints.

(E) A work bench or General Purpose Laboratory shall be provided for Equipment Maintenance and Repair. It shall be equipped with a standard tool set with mechanical and electronic retention devices.

(3) Stowage and Retrieval

(A) Drawers and cabinets shall be equipped with suitable restraints to allow easy access, removal and restowage of equipment.

(B) Equipment stowage provisions and restraints shall allow for easy identification of the stowed item prior to removal.

(C) Drawer stowage devices shall be equipped with internal lids to prevent small items from drifting from and behind drawers.

(D) Stowage areas shall be compartmented to aid in the control of equipment during crewmen stowage and removal of equipment.

(E) All tools used throughout the space station shall be stowed in one location.

(F) Temporary constraints for equipment shall be available throughout the Space Station.

(4) Private Sleeping Quarters

(A) Private crew quarters shall be designed to be utilized with or without the sleep restraints. The private crew quarters shall be equipped for

television viewing, individual bulletin boards, the ability to control temperatures and ventilation, trash stowage, stowage for personal items, and personalized decor.

(B) Private crew quarters ceiling shall be designed to permit easy ingress and egress to and from the sleep restraint.

(C) Private Crew quarters shall be designed for convenient use with and without the sleep restraint. Adequate volume shall be provided to allow rapid exit from sleep restraint.

(D) Private crew quarters ceiling to floor length shall exceed the sleep restraint length.

(5) Windows

(A) The window design shall provide the capability for cleaning windows, inside and out, from the inside. An exterior window cover shall be provided that can be moved into place to protect the exterior window surface when not in use.

(B) The window design shall provide a positive means for removal of moisture from the space between multiple pane windows (assumes seal failure).

(C) It is desirable to integrate a viewing window into the private crew quarters and the wardroom area.

(D) Wherever viewing windows are provided there shall be a clear area around the window to allow several crewmen to view simultaneously and allow for discussion of observations.

(6) Workstations

(A) Workstations at windows used for operations and science shall be equipped as follows:

- o Mounted Tape Recorder
- o Event Timer
- o Camera Mount
- o Hand Held Camera Rest
- o Adjustable Light
- o Body Restraint
- o Restraints for Checklists

- o CRT Display
- o Moving Map Display of Area Along Flight Path
- o Method for Measuring Angles and Range
- o Horizon Sensor
- o Stabilizing Device for Binoculars
- o Area Lighting Controls
- o Located Out of Traffic
- o Controls and Displays Readable From Any Angle
- o Workstation Hood or Dark Curtains

C. Mobility and Restraint

(1) Locomotion

(A) Equipment located in traffic routes and work station areas shall be designed to accommodate crew movement. Equipment shall be designed to accommodate impact forces imparted by crewmen during translation movement.

(B) Large items that require moving in the station shall have built-in handles or gripable structural or mechanical parts.

(2) Restraint Aids

(A) Crew body restraints and work done in restraints shall avoid sitting, bending, stooping, or crouching body positions.

(B) A positive grid/shoe restraint system or equivalent shall be provided for crewmen use throughout the Space Station.

(C) Restraint systems shall permit the crewmen to readily change position within reasonable working limits.

(D) Work stations shall be designed for zero-g body positive with restraints adjustable in body length and torso length.

(E) Whenever a crewman is required to engage or disengage foot restraints, suitable, grabable, conveniently located handholes shall be provided.

(F) Adequate personnel restraints shall be provided in the Waste Management Area.

(G) A simple readily applied and available restraint aid shall be provided for temporarily holding small items such as tools, bolts, screws, and washers.

(3) Equipment Restraints

(A) Each work station shall be suitably equipped with positive restraints for conveniently holding checklists, books, and manuals, open to a particular page and maintaining adequate visibility and lighting.

(D) Food and Drink

(1) Food

(2) Drink

(3) Galley

(4) Dining

(E) Clothing

(1) Duty Garments

(2) Off-duty Garments

(3) Sleepware

(4) Protective Clothing

(F) Personal Hygiene

(1) Body Waste Collection

(A) The solid waste fecal-collector shall be oriented in the Earth-g position.

(2) Personal Cleanliness

(A) A handwashing bubble shall be available for use outside the Waste Management Facility.

(3) Bathing

(A) The shower facility shall satisfy the following requirements and characteristics.

- o Easy to use
- o Hot and cold running water controlled with a mixing valve
- o Permit hair and scalp washing
- o Use airflow system to remove water
- o Provide temperature controlled (heated) dressing area

G. Housekeeping

(1) Cleaning

(A) All parts of the Waste Management system shall be designed to be easily disassembled for daily cleaning.

(B) The Food Preparation and wardroom eating areas shall be designed to be easly cleaned following food spills.

(2) Refuse Collection and Disposal

Trash compactors shall be considered for reducing the storage and transport volume for inorganic waste.

H. **Communications**

(1) IVA Communications

(A) The communication system intercom shall be flexible in operation and readily moveable. A duplex portable wireless intercom shall be considered as part of the intercom communication system.

(2) Person to Ground Communication

(3) External Communications

(A) The communication system shall provide a method for signaling use state. A light or equivalent indicator shall show when the ground is transmitting and when the spacecraft is transmitting.

(B) The communication system shall be designed to allow the operation to follow the information flow.

I. **Crew Activity**

(1) Leisure Recreation

(2) Exercise

2. **Crew Support**

A. **Scheduling**

(1) The ground planning functions shall define objectives for block period of times. The flight crews shall make their daily work schedules based on general programs and checklists set in the computer and responding to ground defined objectives. The details of daily operations shall be defined by the flight crew.

B. **Emergency Provisions and Planning**

C. **Man-Machine Interface**

(1) Anthropometric

(2) Displays and Controls

(A) A standardized approach shall be established for design of all displays and controls used by the flight crew.

(3) Information Processing

(4) Checklists and Procedures

(5) Automation

3.2.2.1.12 Thermal Control

3.2.2.1.13 Health Maintenance

3.2.2.1.14 Fluid Management

The fluid and gas systems shall be designed to be serviced from the interior of the Spacecraft. Fluid/gas connections shall be configured for crew inspection and test for leaks.

3.2.2.2 Ground Systems Design

3.2.3 Logistics *(Para. 2.6.8)*

Logistics requirements and for the Space Systems are defined in these paragraphs. Constraints imposed by the STS and the Space Station cargo module are defined.

3.2.4 Personnel and Training

Personnel requirements, constraints, and training requirements for the flight crew and support personnel are defined.

3.2.5 Space Station System Interface Characteristics *(Para. 3.0)*

The System Level Program Relationships are shown in the Specifications Tree Figure 3.2.5-1. System Interface Characteristics are described:

3.2.5.1 Space Transportation System

3.2.5.2 Space Station Mission Payloads

1. Platforms and Freeflyers
2. Attached Payloads
3. Payload Elements

3.2.5.3 Orbital Transfer Vehicles

1. Ground Based OTV
2. Space Based OTV

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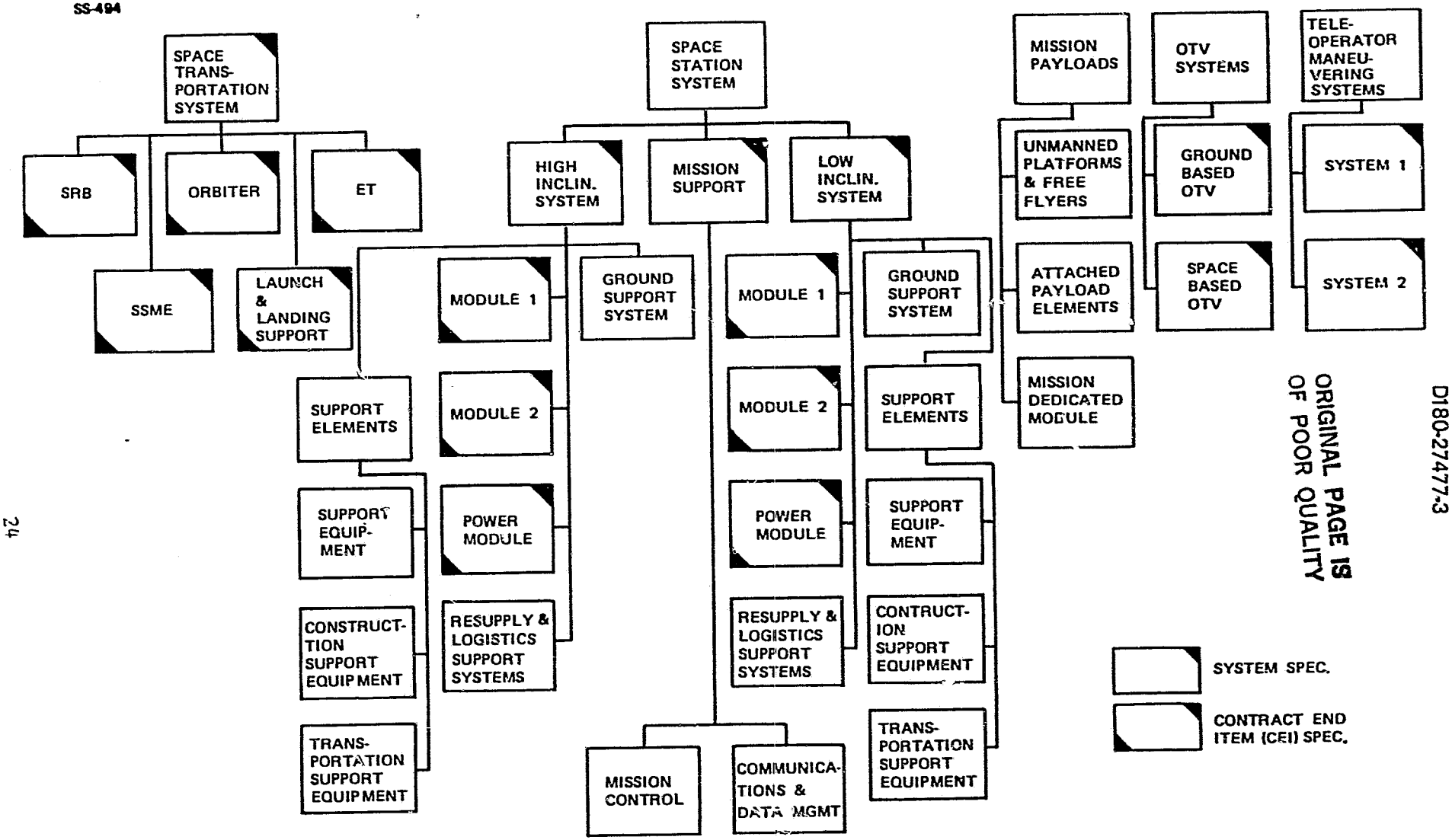

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Figure 3.2.5-1. System Specifications and Contract End Items

3.2.5.4 Teleoperator Maneuvering Systems

3.2.5.5 Mission Payloads

3.3 SPACE STATION SYSTEM END ITEM PERFORMANCE

The Space Station System End Item Contract End Items are as shown in Figure 3.2.5-1. *It should be noted in the High Inclination and the Low Inclination System that many of the end items are identical between the two systems. In those cases there will be common C.E.I.'s.*

The Space Station System end item performance and characteristics are defined in the following paragraphs.

3.3.1 Module 1
3.3.2 Module 2
3.3.3 Power Module
3.3.4 Resupply and Logistics Support Systems
3.3.4.1 Logistics Module
3.3.5 Support Elements
3.3.6 Support Equipment
3.3.6.1 Manipulator System
3.3.6.2 Payload Handling Tools
3.3.6.3 EVA Workstation
3.3.6.4 Mobile Cherry picker
3.3.7 Construction Support Equipment
3.3.7.1 Handling and Positioning Aid
3.3.7.2 Beambuilder
3.3.8 Transportation Support Equipment

3.4 GROUND COMPLEX PERFORMANCE AND DESIGN CHARACTERISTICS

The ground system performance and design characteristics will be defined in this section.

3.5 OPERABILITY

3.5.1 Reliability *(para. 2.6.3)*

3.5.2 Maintainability *(para. 2.6.2)*

3.5.3 Useful Life

3.5.4 Safety *(para. 2.6.1)*

3.5.5 Human Performance

Skill

Size

Human Engineering Criteria

3.5.6 Transportability

3.5.7 Hazardous Materials and Component

3.6 SYSTEM DESIGN AND CONSTUCTION STANDARDS

3.6.1 Specs and Stds.

3.6.2 Materials, Parts and Processes

3.6.3 Parts Selection

3.6.4 Corrosion

3.6.5 Interchangeability and Replaceability

3.6.6 Electromagnetic Compatibility

3.6.7 Identification and Marking

3.6.8 Storage

3.6.9 Drawing Standards

3.6.10 Coordinate System

3.6.11 Traceability

3.6.12 Electrical Bonding

3.6.13 Electrical Installations

3.6.14 GSE/Facility Des.

3.6.15 Screw Threads

3.6.16 CEI Format

3.6.17 Pyro Technics

3.6.18 Lightning Protection

3.7 QUALITY ASSURANCE *(para. 2.6.9)*

4.0 VERIFICATION *(para. 2.6.7)*

5.0 PREPARATION FOR DELIVERY

6.0 NOTES

10.0 APPENDIX

10.1 Natural Environments

10.2 Induced Environments

APPENDIX 1

SUMMARY OF STUDY TASKS AND FINAL REPORT TOPICAL CROSS REFERENCE

SUMMARY OF STUDY TASKS

The study accomplished 3 major objectives:

1. Identified, collected, and analyzed science, applications, commercial, national security, technology development and space operations missions that require or benefit by the availability of a permanently manned space station. The space station attributes and characteristics that will be necessary to satisfy these requirements were identified.
2. Identified alternative space station architectural concepts that would satisfy the user mission requirements.
3. Performed programmatic analyses to define cost and schedule implications of the various architectural options.

Figure A-1 shows the summary task flow that was used to accomplish these objectives.

In Tasks 1.1 thru 1.5, missions were identified, screened, and their needs and benefits analyzed. Mission investigators were assigned to each of the mission classes (science and applications, commercial, technology development, space operations, and national security). In general, these investigators (and their supporting subcontractors) contacted potential users and analyzed available data to characterize potential mission needs. They worked in conjunction with designers and operations analysts to characterize the potential payloads and operational interfaces. In Task 1.6, the missions were allocated to orbits, and were assigned to platforms, free-flyers, or space stations, as appropriate. During Task 1.7, the various missions were integrated into time-phased mission models. The time-phasing took into account available budgetary constraints, prioritization, time sequencing constraints, and transportation availability. A computer program was used to process the integrated time-phased mission model to derive a year-by-year shuttle manifest schedule. The computer program was also used for Task 1.8 to derive the integrated time-phased space station accommodation requirements, i.e., power and thermal demands, berthing requirements, and crew skills. These mission analyses have been reported in Volume 2 of the final report.

Also included in Volume 2 are the results from Task 1.10. In this task, some of the primary commerical opportunities were examined to define the economics of the use of a space station and to define the benefits of doing business on a space station relative to doing it using the shuttle.

In Task 1.9, mission requirements and space station design requirements were identified. An aggregate of these requirements are reported in Volume 3.

Volume 4 of the final report contains the results from Tasks 2.1, 2.2 and 3. Specifically in Task 2.1, a methodology for defining realistic architectural options was established. This methodology was applied using the requirements defined in the previous tasks. From this, we have created 3 architectural options and have shown some reference space station configuration concepts for each architectural option. Task 2.2 was performed to obtain analysis and trades of some of the principle subsystems, i.e., data management, environmental control and life support, and habitability. Task 3 provides the analyses of programmatics and cost options associated with the concepts derived during the study.

A cross reference guide to enable locating study topics within the volumes and volume sections of the final report is presented in Table A-1.

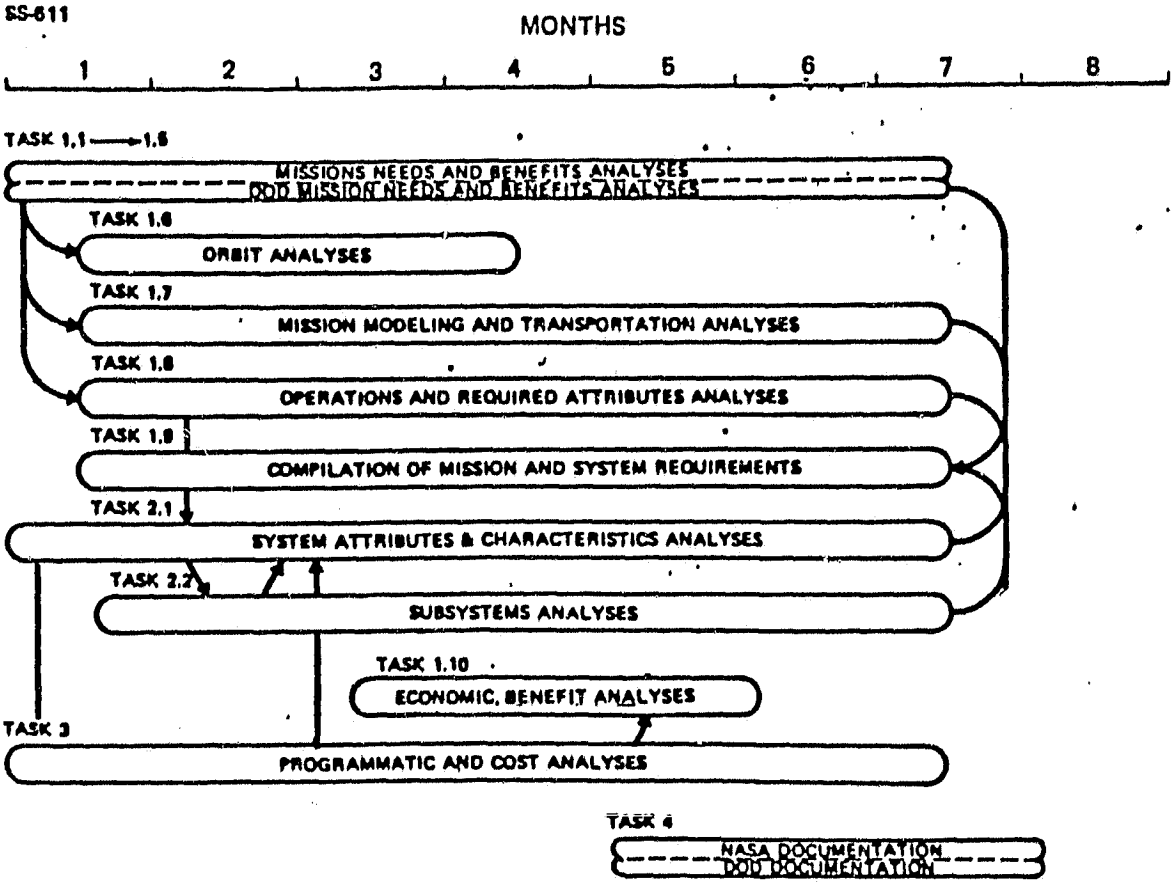

Figure A-1. Summary Diagram Outlines Major Task Traffic

TABLE A-1

Final Report Topical Cross Reference Guide

Topic	Vol. 1 Exec Summ	Vol. 2 Mission Anal	Vol. 3 Rqm'ts	Vol. 4 Archit	Vol. 5 DoD	Vol. 6 Final Brief	Vol. 7-1 Sci/App Data Book	Vol. 7-2 Commer Data Book	Vol. 7-3 Tech Demo Data Book	Vol. 7-4 Archit Data Book	Vol. 7-5 Mission Data Book
Commercial Missions											
o Communication Satellites	o	3.2.1				o		o			
o Reconfigurable o Multibeam											
o Materials Proc.	o	3.2.2		I-1.3.2.3, 1.2.2.1		o		o			
o Semiconductors o Biological o Glass Fibers											
o Earth Observation		3.2.3									
Industrial Services		3.2.4						o			
o Crew Selection & Training o In-Space OPS											
Technology Demo's	o	3.3				o			o		
Space Operation	o	3.4				o					
o Construction o Flight Support o Servicing											

TABLE A-1

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Science & Applications Missions											
o Space Environment Missions	o	3.1.2				o	o				
o Astrophysics Missions	o	3.1.3				o	o				
o Earth Environment Missions	o	3.1.4				o	o				
o Life Sciences Missions	o	3.1.5				o	o				
o Materials Science Missions	o	3.1.6					o				
Scenarios of Operational Capabilities	o	4.0, 5.0				o					
o Mission Constrained											
o Station Constrained											
o No Space Station											

TABLE A-1

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Topic	Vol. 1 Exec Summ	Vol. 2 Mission Anal	Vol. 3 Rqm'ts	Vol. 4 Archit	Vol. 5 DoD	Vol. 6 Final Brief	Vol. 7-1 Sci/App Data Book	Vol. 7-2 Commer Data Book	Vol. 7-3 Tech Demo Data Book	Vol. 7-4 Archit Data Book	Vol. 7-5 Mission Data Book
Mission Requirements Summary		5.0									o
o Low Inclination Space Station	o	5.2,5.3	3.2.1	I-1.2.2.4		o					o
o High Inclination Space Station	o	5.2,5.3		I-1.2.2.4		o					o
o Platform only	o	5.4				o					o
o Manifesting o Shuttle o OTV o TMS	o	5.2, 5.3, 5.4				o					o
o Crew Size	o	5.2,5.3 5.4	3.2.1			o					o
o Crew Skills		5.2.5.3 3.1.2.5, 3.1.3.5, 3.1.4.5, 3.1.5.5, 3.2.1.5, 3.2.2.6, 3.2.3 3.3		II-2.2.3							o

TABLE A-1

Final Report Topical Cross Reference Guide

Topic	Vol. 1 Exec Summ	Vol. 2 Mission Anal	Vol. 3 Rqm'ts	Vol. 4 Archit	Vol. 5 DoD	Vol. 6 Final Brief	Vol. 7-1 Sci/App Data Book	Vol. 7-2 Commer Data Book	Vol. 7-3 Tech Demo Data Book	Vol. 7-4 Archit Data Book	Vol. 7-5 Mission Data Book
Mission Requirements Summary (Continued)											
o Accommodations Reqm'ts	o	2.2	3.2.1			o					o
o Power		5.2,5.3 5.4	I-1.2.1.2, 1.2.2.4 1.2.3.3 1.2.3.4								
o Internal Vol											
o Berthing Ports											
Benefits		6.0									
o Semiconductor Manufacturing	o	6.2				o					o
o Glass Fiber Manufacturing	o	6.3				o					o
o Communications Satellite Assembly	o	6.4				o					o
o Biological Materials Manufacturing	o	6.5				o					o

TABLE A-1

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Mission Analysis											
o Manifesting Analysis Software	o	2.2				o					o
o Accommodations & Crew Activity Analysis Software o Crew Skills o Crew Size o Berthing Ports o Electrical power o Internal volume	o	2.2				o					o
Design Requirements											
o Mission Accommodation Reqm'ts		5.0	3.2								
o Interfaces o Berthing/Docking Port				II-10.0 I-1.3.2.1						o	
o Hangar		3.3		I-1.3.2.2							

TABLE A-1

Final Report Topical Cross Reference Guide

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Architectural Options											
o Architecture Development Methodology	o			I-1.1		o				o	
o Space Station Architectural Options	o			I-1.2		o				o	
Build-up and Growth	o	5.0		I-1.2.3.4, 1.3.1.3, 1.3.2.3, 1.3.3.3							
Data Management											
o Architecture				II-3.2						o	
o In-Flt Checkout				II-3.3						o	
o Space-Ground Integration				II-3.4						o	
o Ground Lab				II-3.5						o	
o Software Devel.				II-3.6						o	
o Hardware Stds				II-3.7						o	
o Software Stds				II-3.8						o	
o Verif/Valid.				II-3.9						o	

TABLE A-1

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Logistics/Resupply											
o Logistics Module				II-7.1, 7.3,7.4							
o Resupply Reqm'ts				II-7.2							
Environmental Control and Life Support Subsystem				II-5.0						o	
o ECLS Evolution				II-5.2.1, 5.3.2						o	
o Safe Haven Logistics Module				II-5.2.1						o	
o Air Revitalization System				II-5.0,5.3.2						o	
o Water Revitalization System				II-5.0,5.3.2						o	
o Performance and Loads Specification										o	
o Overboard Venting				II-5.2.1,5.2.2						o	
o Architecture				II-5.2.1						o	
o Water Recovery System				II-5.0,5.3.2						o	
o CO_2 Concentration				II-5.0,5.3.2						o	
o Regenerative-Fuel-Cell-Based ECLS				II-5.0,5.2.1, 5.3.2						o	
o Recommendations				II-5.0, 5.3.2						o	
EVA/EMU				II-5.0, 5.2.2						o	

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Communications & Tracking Subsystem			3.2.2.1.11	II-4.0						o	
Manipulator System				II-6.0						o	
Pointing Systems				II-8.0						o	
Thermal Management				II-9.0						o	
Crew				II-2.0							
o Tasks				II-2.2						o	
o Skills		5.2.5.3 3.1.2.5, 3.1.3.5, 3.1.4.5, 3.1.5.5, 3.2.1.5 3.2.2.6, 3.2.3 3.3		II-2.2.3							
o Capabilities				II-2.2.2						o	
o Role Relationships				II-2.3.2						o	
o Accommodations			3.2.2.1.11	II-2.4						o	

TABLE A-1

Final Report Topical Cross Reference Guide

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Crew (Continued)											
o Habitability	o		3.2.2.1.11	II-2.0,2.4						o	
o IVA Work Stations				II-2.5.2						o	
o EVA Work Stations				II-2.5.3 II-5.2.2						o	
o Maintenance				II-2.5.4							
o Stowage			3.2.2.1.11							o	
o Windows			3.2.2.1.11	II-2.4.1						o	
o Hygiene			3.2.2.1.11	II-2.4.2.4						o	
o Scheduling			3.2.2.1.11	II-2.3.1						o	

APPENDIX 2

KEY TEAM MEMBERS

KEY TEAM MEMBERS

Subject	Boeing Team	Subcontractor Team	
Study Manager	Gordon Woodcock	ADL:	Dr. Peter Glaser
		Battelle:	Kenneth E. Hughes
		ECON:	John Skratt
		ERIM:	Albert Sellman
		Hamilton Standard:	Harlan Brose
		Intermetrics:	John Hanaway
		Life Systems:	Franz Shubert
		MRA:	Col. Richard Randolph (Ret.)
		NBS:	Dr. B. J. Bluth
		RCA:	Dr. Herbert Gurk
		SAI:	Dr. Hugh R. Anderson
Technology Manager	Dr. Richard L. Olson		
Mission Analysis			
Science & Applications	Dr. Harold Liemohn David Tingey (Earth Obs.) Dr. Derek Mahaffey (Mission Integration) Melvin W. Oleson (Life Sciences) Dr. Robert Spiger (Plasma physics, astro-physics, solar physics)	SAI:	Dr. Hugh R. Anderson (Environmental Science) Dr. Peter Hendricks (Meterology/ Oceanography) Dr. Gil Stegen Dr. John Wilson (Life Sciences) Dr. Robert Loveless (Integration) Dr. Robin Muench Dr. Stuart Gorney (Life Sciences) Ms. Monica Dussman (Life Sciences)
		ERIM:	Albert Sellman (Earth Obs.) Dr. Irvin Sattinger (Earth Obs.)
Commercial	Dr. Harvey Willenberg	RCA:	Dr. Herbert Gurk Thaddeus (Ted) Hawkes
		ADL:	Dr. Peter Glaser
		Battelle:	Dr. Kenneth E. Hughes
		MRA:	Col. Richard Randolph (Ret.) Robert Pace

KEY TEAM MEMBERS (Cont'd)

Subject	Boeing Team	Subcontractor Team	
Mission Analysis (Cont'd)			
Technology Demonstrations	George Reid Dr. Alan G. Osgood David S. Parkman Steve Robinson Richard Gates Tim Vinopal		
National Defense	Robert S.Y. Yoseph	ERIM:	Mirko Najman
Space Operations	Keith H. Miller		
Architecture and Subsystems			
Architecture & Configurations	John J. Olson Brand Griffin Tim Vinopal David S. Parkman Steve Robinson		
Communications		RCA:	Donald McGiffney
Crew Systems	Keith H. Miller George Reid Dr. Alan G. Osgood	NBS:	Dr. B. J. Bluth
Data Management and Software	Les Holgerson	Intermetrics:	John Hanaway
ECLSS	Keith H. Miller	Ham Std:	Harlan Brose Ross Cushman Al Boehm Ken King Todd Lewis
		Life Systems:	Dr. R. A. Winveen Franz Schubert Dr. Dennis B. Heppner
Operations Analysis	Keith H. Miller George Reid Dr. Alan G. Osgood		
Orbit Analysis	Dani Eder		

KEY TEAM MEMBERS (Cont'd)

Subject	Boeing Team	Subcontractor Team	
Architecture and Subsystems (Cont'd)			
Orbit/Survivability Analysis	Stephen W. Paris Merri Anne Stowe		
C^3I	H. Paul Janes		
Radiation Effects	Dr. William C. Bowman		
Requirements Analysis	Lowell Wiley		
Programmatics & Cost			
Cost Analysis	Ken verGowe	ECON:	Ed Dupnick
Programmatics	Gordon Woodcock		

APPENDIX 3

ACRONYMS AND ABBREVIATIONS

LIST OF ACRONYMS AND ABBREVIATIONS

AAP	Airlock Adapter Plate
AC	Alternating Current
ADM	Adaptive Delta Modulation
AM	Airlock Module
APC	Adaptive Predictive Coders
APSM	Automated Power Systems Management
ACS	Attitude Control System
ARS	Air Revitalization System
ASE	Airborn Support Equipment
BIT	Built in Test
BITE	Built in Test Equipment
CAMS	Continuous Atmosphere Monitoring System
C&D	Controls and Displays
C&W	Caution and Warning
CCA	Communications Carrier Assembly
CCC	Contaminant Control Cartridge
CCTV	Closed Circuit Television
CEI	Critical End Item
CER	Cost Estimating Relationship
CF	Construction Facility
CMG	Control Moment Gyro
CMD	Command
CMDS	Commands
CO_2	Carbon Dioxide
CPU	Computer Processor Units
CRT	Cathode Ray Tube
dB	Decibels
DC	Direct Current
DCM	Display and Control Module
DDT&E	Design, Development, Test, and Evaluation
DOD, DoD	Department of Defense
DT	Docking Tunnel
DM	Docking Module
DMS	Data Management System
DSCS	Defense Satellite Communications System
ECLSS	Environmental Control/Life Support System
EDC	Electrochemical Depolarized CO_2 Concentrator
EEH	EMU Electrical Harness
EIRP	Effective Isotropic Radiated Power
EMI	Electromagnetic Interference
EMU	Extravehicular Mobility Unit
EPS	Electrical Power System
ET	External Tank
EVA	Extravehicular Activity
EVC	EVA Communications System
EVVA	EVA Visor Assembly
FM	Flow Meter
FMEA	Failure Mode and Effects Analysis
ftc	Foot candles
FSF	Flight Support Facility
FSS	Fluid Storage System
GaAs	Gallium Acsenide

LIST OF ACRONYMS AND ABBREVIATIONS (Continued)

GN&C	Guidance, Navigation and Control
GEO	Geosynchronous Earth Orbit
GHZ	Gigahertz
GPC	General Payload Computer
GPS	Global Positioning System
GSE	Ground Support Equipment
GSTDN	Ground Satellite Tracking and Data Network
GFE	Government Furnished Equipment
GTV	Ground Test Vehicle
HLL	High Level Language
HLLV	Heavy Lift Launch Vehicle
HM	Habitat Module
HMF	Health Maintenance Facility
HPA	Handling and Positioning Aide
HUT	Hard Upper Torso
Hz	Hertz (cycles per second)
ICD	Interface Control Document
IDB	Insert Drink Bag
IOC	Initial Operating Capability
IR	Infrared
IVA	Intravehicular Activity
JSC	Johnson Space Center
KBPS	Kilo Bits Per Second
KM, Km	Kilometers
KSC	Kennedy Space Center
lbm	Pounds Mass
LCD	Liquid Crystal Display
LCVG	Liquid Cooling and Ventilation Garment
LED	Light Emitting Diode
LEO	Low Earth Orbit
LiOH	Lithium Hydroxide
LM	Logistics Module
LPC	Linear Predictive Coders
LRU	Lowest Replaceable Unit
LSS	Life Support System
LTA	Lower Torso Assembly
LV	Launch Vehicle
lx	Lumens
MBA	Multibeam Antenna
mbps	Megabits per second
MHz	Megahertz
MMU	Manned Maneuvering Unit
MM-Wave	Millimeter wave
MOTV	Manned Orbit Transfer Vehicle
MRWS	Manned Remote Work Station
MSFN	Manned Space Flight Network
N/A	Not Applicable
NBS	National Bureau of Standards
NSA	National Security Agency
N	Newton
NiCd	Nickel Cadmium
NiH_2	Nickle Hydrogen

LIST OF ACRONYMS AND ABBREVIATIONS (Continued)

Nm,nm	Nautical miles
N/m^2	Newtons per meter squared
OBS	Operational Bioinstrumentation System
OCS	Onboard Checkout System
OCP	Open Cherrypicker
OMS	Orbital Manuevering System
OTV	Orbital Transfer Vehicle
PCM	Pulse Code Modulation
PCM	Parametric Cost Model
PEP	Power Extension Package
PIDA	Payload Installation and Deployment Apparatus
P/L	Payload
PLSS	Portable Life Support System
PM	Power Module
POM	Proximity Operations Module
ppm	Parts per Million
PRS	Personnel Rescue System
PSID	Pounds per Square Inch Differential
RCS	Reaction Control System
REM	Roentgen Equivalent Man
RF	Radio Frequency
RFI	Radio Frequency Interference
RMS	Remote Manipulator System
RPM	Revolutions Per Minute
RPS	Real-time Photogrammetric System
SAF	Systems Assembly Facility
SAWD	Solid Amine Water Desorbed
SPGaAs	Space Produced Gallium Arsenide
scfm	Standard Cubic Feet per Minute
SCS	Stability and Control System
SCU	Service and Cooling Umbilical
SDV	Shuttle - Derived Vehicle
SDHLV	Shuttle - Derived Heavy Lift Vehicle
SEPS	Solar Electric Propulsion System
SF	Storage Facility
SM	Service Module
SOC	Space Operations Center
SOP	Secondary Oxygen Pack
SRB	Solid Rocket Booster
SRMS	Shuttle Remote Manipulative System
SRU	Shop Replacable Units
SSA	Space Suite Assembly
SSME	Space Shuttle Main Engine
STS	Space Transportation System
SSP	Space Station Prototype
STAR	Shuttle Turnaround Analysis Report
STDN	Spaceflight Tracking and Data Network
STE	Standard Test Equipment
TBD	To Be Determined
TDRSS	Tracing and Data Relay Satellite System
TFU	Theoretical First Unit
TGA	Trace Gas Analyzer

LIST OF ACRONYMS AND ABBREVIATIONS (Continued)

TIMES	Thermoelectric Integrated Membrane Evaporation System
TLM	Telemetry
TM	Telemetry
TMS	Teleoperator Maneuvering System
TT	Turntable/Tilttable
TV	Television
UCD	Urine Collection Device
VCD	Vapor Compression Distillation
VDC	Volts Direct Current
VLSI	Very Large Sacle Integrated Circuits
VSS	Versatile Servicing Stage
WBS	Work Breakdown Structure
WMS	Waste Management System